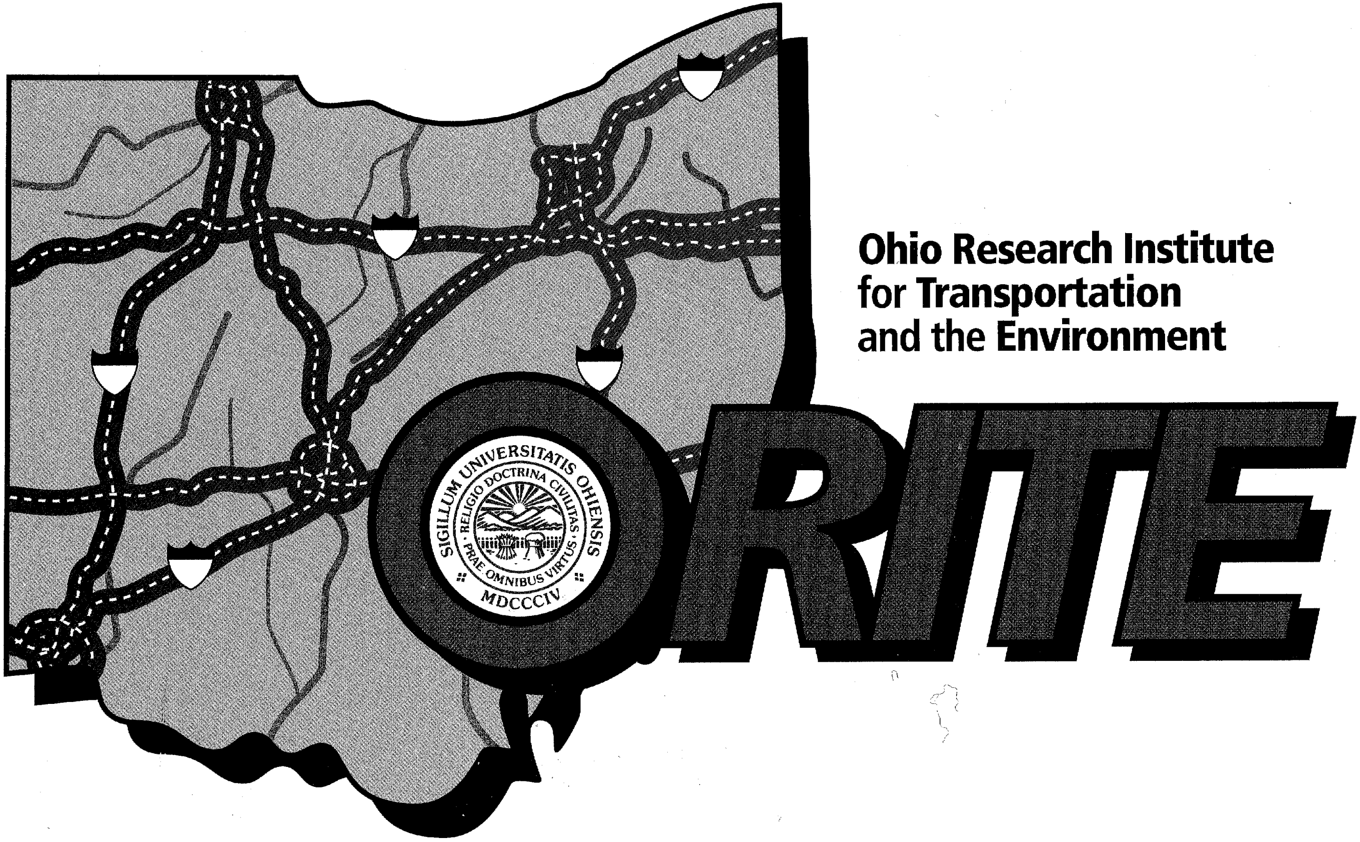

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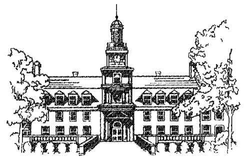

Subgrade Variability on the Ohio SHRP Test Road

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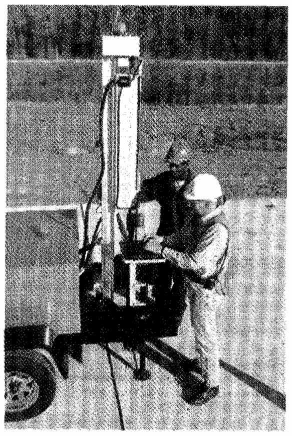


Introduction

Construction of the Ohio SHRP Test Road was initiated in 1994. One of the early priorities was to provide a uniform subgrade for the forty, 500-foot long test sections included in the project and, thereby, permit a more direct comparison of section performance. Preliminary borings indicated a relatively consistent, predominantly AASHTO A-6 soil along the three-mile long site and the topography was flat. To avoid localized pockets of weakness, provisions were made in the construction specifications and plan notes to replace unsuitable material with A-6 soil from a borrow pit. Fortunately, acceptable borrow was available from a field adjoining the project. This paper documents the extent to which subgrade uniformity was achieved on the Ohio SHRP Test Road.

As construction proceeded, considerably more subgrade undercutting was required than originally anticipated. Much of the undercutting was due to the presence of old basements, wells, septic fields, etc. left when this section of U.S. 23 north of Delaware, Ohio was upgraded from a two-lane pavement to a four-lane divided facility in the 1960s. Undercutting depths varied from a few inches to over ten feet. Moisture and density were monitored with a nuclear density gauge to ensure proper compaction as the subgrade was brought up to its final elevation. It was then proof rolled to identify localized areas of weakness. Once the subgrade in each test section was approved, the Falling Weight Deflectometer (FWD) was used to measure in-situ stiffness at 15.2 meter (50-ft.) intervals in the centerline and right wheel path of each SHRP test section. With the exception of Sections 390159 and 390264, the subgrade in all mainline sections was finished by September 1995, and the bases were completed before winter set in that year. The subgrade in Sections 390159 and 390264 was finished in June 1996, and final paving was completed on all mainline sections before being opened to traffic on August 14-15, 1996.

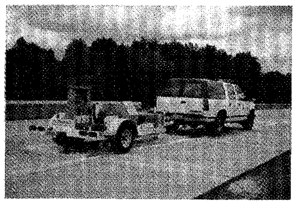
Testing

Instrumentation was placed in the sampling and testing portion of 18 test sections to monitor subsurface environmental conditions throughout the project. Sensors were installed to measure temperature, moisture and frost to a depth of six feet in accordance with SHRP protocol. Piezometer wells were added along the edge of nine test sections to record the elevation of the water table. Bulk samples of subgrade soil were obtained from 12 sections and tested in the laboratory for various mechanical properties. Also, a series of Dynamic Cone Penetrometer (DCP) tests were performed in Section 390101 during a forensic study to determine the cause of early rutting in the wheel paths. The following summarizes the results of these investigations:

AASHTO Soil Classification: Of ten sections sampled on the mainline pavement, six were identified as A-6, three were identified as A-4/A-4a, and one was identified as A-7-6. Two samples obtained from the ramp where the SPS-8 experiment was located were identified as A-4/A-4a.

Subgrade Density and Moisture: After the subgrade in each test section was approved, nuclear density measurements were typically taken at Stations 1+00, 2+50 and 4+00 in the centerline of the test lane and submitted for inclusion in the LTPP database. Averages of these readings are shown in the subgrade table.

Gravimetric Moisture Content: During the first two years of service, subsurface time-domain reflectometry probes (TDR) located in the upper portion of the subgrade did not detect any significant seasonal moisture



effects. Probes placed 0.15-0.45 meters (6-18 in.) below the surface of the subgrade indicated moisture contents of about 20% for all sections. Moisture near the surface of the subgrade varied according to the type of base used, as follows: 12-15% for dense graded aggregate bases (DGAB), around 10% for free draining bases, and 20-40 % for stabilized bases.

FWD: By applying a haversine load pulse to a pavement surface with an FWD and measuring vertical deflection at seven radial distances within the basin generated by the load, the in-situ stiffness of various layers within the system can be determined. For subgrade, deflection under the center of the 300mm (11.8in.) diameter load plate is used with the Boussinesq equation to calculate a composite modulus of elasticity. Subgrade moduli calculated in this manner for test sections in the Ohio SHRP Test Road were highly variable, as indicated in the subgrade table. FWD profiles obtained in each section can be used to identify specific locations with low stiffness.

DCP: This device drives a steel rod into unstabilized bases and soil with a known amount of energy. By continuously monitoring the rate of penetration, the stiffness of various layers can be measured accurately with depth. Three locations (Stations 1+50, 2+65 and 4+00) judged from visual distress and FWD measurements to be an average, the most and the least distressed areas respectively in Section 390101after it had failed, were selected for DCP investigation. These data showed the zones of least resistance to DCP penetration to be between 0.60 and 1.00 meters (24-39 in.) below the top of the base at Station 1+50 (15-40 mm/blow) and between 0.20 and 0.60 meters (8-24 in.) below the top of the base at Station 2+65 (25-150 mm/blow). At Station 4+00, the rates of penetration increased steadily from 10-60 mm/blow over a depth of 1.00 meter (39 in.) below the top of the base. The top of the subgrade was 0.20 meters (8 in.) below the top of the base in this section.

Summary

Coefficients of variation calculated for various subgrade parameters shown in the enclosed summary of results indicate much smaller variations in density and moisture for the 36 mainline test sections (0.04 and 0.18 respectively) than for stiffness (modulus) measured with the FWD (0.54). Stiffness variations within the individual test sections were also rather high. While in-situ stiffness, which is the mode of support in a pavement structure, is related to density, moisture and soil type, there is no clear correlation between these parameters. Data in the table show stiffness and density to be somewhat related, with the effects of moisture on stiffness being unclear.

In addition to the inherent complexity of relating subgrade moisture and density to stiffness, is the manner in which these parameters are measured. Two or three nuclear density measurements were obtained at widely spaced locations in each test section for subgrade approval. These measurements were quite localized and only evaluated material in the top 0.30 meters (12 in.) of the layer being tested. The FWD applies a full-scale load and measures composite stiffness throughout the total depth of subgrade supporting the load. The FWD also requires much less time per reading, thus allowing for a more comprehensive assessment of the surface in question Typically, a total of 21 FWD measurements were taken along the centerline and right wheel path of each test section.

Average subgrade moduli in the 36 mainline test sections, as determined with the FWD and the Boussinesq equation, varied from 34.3-205.3 Mpa (4.97-29.77 ksi) with an average of 104.7 Mpa (15.18 ksi). The standard deviation was 56.8 Mpa (8.24 ksi) and

Water Table

While the water table dropped in the fall and early winter of 1997, it remained stable during the remainder of the year and relatively constant throughout the length of the project. Statistical information are summarized in the following table:

Depth of water table below top of pavement 12/17/96 – 1/22/99, meters (feet)

Section No.	Average		Maximum		Minimum	
	Depth	Elevation	Depth	Elevation	Depth	Elevation
390103	2.60 (8.52)	(946.85)	3.71 (12.17)	(943.20)	1.96 (6.43)	(948.94)
390108	2.00 (6.56)	(946.79)	2.87 (9.42)	(943.93)	1.57 (5.15)	(948.20)
390102*	1.58 (5.18)	(948.51)	1.90 (6.23)	(947.46)	1.26 (4.13)	(949.56)
390104	1.20 (3.94)	(952.06)	1.71 (5.61)	(950.39)	0.80 (2.62)	(953.38)
390901	2.53 (8.30)	(947.22)	3.48 (11.42)	(944.10)	1.70 (5.58)	(949.94)
390204	2.77 (9.09)	(946.47)	3.30 (10.83)	(944.73)	2.39 (7.84)	(947.72)
390212	1.73 (5.68)	(951.47)	2.12 (6.96)	(950.19)	1.47 (4.82)	(952.33)
390201	1.60 (5.25)	(949.62)	1.77 (5.81)	(949.06)	1.38 (4.53)	(950.34)
390208	2.56 (8.40)	(945.96)	3.60 (11.81)	(942.55)	2.02 (6.63)	(947.73)

*Sensor destroyed after the 3/12/97 reading

Laboratory Tests

Resilient moduli (not the same as in-situ moduli calculated from FWD data) measured with a triaxial pressure chamber varied little with confining pressure but decreased dramatically with increased deviator stress. The higher the clay content, the more sensitive resilient modulus was to moisture content. The following table summarizes these laboratory data at the optimum moisture content:

Soil Type	Moisture (%)	Unit Dry Weight		Deviator Stress		Resilient Modulus	
		(kN/m³)	(pcf)	(kPa)	(psi)	(Mpa)	(ksi)
A-4	17	17.2	109.5	13.8	2.0	130	18.85
				27.6	4.0	90	13.05
				41.4	6.0	75	10.88
A-6	12	18.3	116.6	13.8	2.0	125	18.13
				27.6	4.0	90	13.05
				41.4	6.0	70	10.15
A-7-6	10-13	18.1	115.3	13.8	2.0	160	23.20
				27.6	4.0	120	17.40
				41.4	6.0	100	14.50

Summary of Subgrade Tests

Section No.	Soil Classification	Nuclear Density Readings			In-Situ Modulus - FWD				
		Dry Unit Weight		Moisture Content (%)	Average		Std. Deviation		CV
		pcf	kg/m3		Mpa	ksi	Mpa	ksi	
SPS-1									
390101		116.8	1870.4	8.9	80.6	11.69	40.1	5.81	0.50
390102		124.6	1995.9	8.3	140.5	20.37	58.3	8.45	0.41
390103		119.8	1919.0	7.7	108.2	15.69	30.2	4.38	0.28
390104		119.7	1918.0	9.2	116.2	16.85	48.7	7.06	0.42
390105		117.6	1883.8	9.7	107.2	15.54	22.8	3.31	0.21
390106		123.4	1976.2	10.0	123.3	17.88	40.9	5.93	0.33
390107	A-7-6	121.3	1942.5	6.8	115.6	16.76	39.4	5.71	0.34
390108		117.4	1881.1	8.5	130.7	18.95	44.0	6.38	0.34
390109		119.7	1917.9	9.7	79.4	11.51	39.2	5.68	0.49
390110	A-4/A-4a	118.0	1889.7	9.7	89.3	12.95	37.5	5.44	0.42
390111	A-6	121.3	1943.6	9.7	124.7	18.08	62.0	8.99	0.50
390112		121.9	1953.2	8.7	95.3	13.82	43.3	6.28	0.45
390159		118.9	1905.1	11.3	39.8	5.77	22.0	3.19	0.55
390160	A-4/A-4a	123.1	1971.8	8.5	128.5	18.63	38.6	5.60	0.30
SPS-9									
390901		126.2	2021.5	9.7	186.0	26.97	99.6	14.44	0.54
390902	A-4/A-4a	122.2	1958.0	10.7	106.9	15.50	47.8	6.93	0.45
390903		126.1	2020.4	8.8	98.8	14.33	41.1	5.96	0.42
SPS-2									
390201		119.6	1916.3	11.1	62.4	9.05	28.6	4.15	0.46
390202	A-6	124.6	1995.4	10.4	123.4	17.89	70.0	10.15	0.57
390203		120.4	1928.6	8.4	103.0	14.94	28.2	4.09	0.27
390204		124.5	1994.3	9.8	205.3	29.77	95.4	13.83	0.46
390205	A-6	118.6	1899.3	11.0	64.3	9.32	37.1	5.38	0.58
390206		120.0	1921.7	10.1	87.8	12.73	46.1	6.68	0.53
390207	A-6	120.9	1936.1	8.2	117.8	17.08	36.2	5.25	0.31
390208		115.2	1845.3	9.3	112.7	16.34	39.0	5.66	0.35
390209		118.1	1891.8	11.7	71.6	10.38	54.1	7.84	0.76
390210		116.0	1858.7	8.8	71.1	10.31	31.4	4.55	0.44
390211	A-6	119.7	1917.4	9.4	109.3	15.85	21.2	3.07	0.19
390212		126.0	2017.8	9.2	140.9	20.43	49.0	7.11	0.35
390259		115.0	1842.1	8.7	79.0	11.46	33.9	4.92	0.43
390260		121.4	1945.2	11.6	101.5	14.72	41.6	6.03	0.41
390261		120.7	1933.9	9.0	124.1	17.99	43.9	6.37	0.35
390262	A-6	120.4	1929.7	8.9	107.8	15.63	42.6	6.18	0.40
390263		119.4	1912.6	11.3	93.7	13.59	42.7	6.19	0.46
390264		112.4	1799.9	13.4	34.3	4.97	15.8	2.29	0.46
390265		121.9	1953.2	8.6	88.7	12.86	18.3	2.65	0.21
	Average	120.7	1930.8	9.6	104.7	15.18	42.5	6.16	0.41
	Std. Dev.	4.3	68.6	1.8	56.8	8.24			
	Coef. Of Var.	0.04	0.04	0.18	0.54	0.54			

the coefficient of variation was 0.54. This six-fold difference in average moduli can have a dramatic effect on the performance of highway pavements, especially those designed for limited service or those exposed to heavy volumes of truck traffic. Add to this range in moduli the large coefficients of variation observed within test sections, and even larger differences in moduli become apparent throughout the project. Two examples of poor subgrade are in Sections 390159 and 390264, which were constructed a year later than the other mainline sections. Section 390264 had the lowest density and stiffness, and the highest moisture content of all the sections in the mainline pavement. Variations in standard pavement construction are likely to be even more dramatic.

It is interesting to note the order in which test sections have failed to date on the Ohio SHRP Test Road. By the summer of 1998, four sections on the mainline SPS-1 pavement had been removed and replaced. Sections 390102 and 390107 rutted badly within days of being opened to traffic. Section 390101 displayed similar distress a few weeks later. After less than a year of service, Section 390105 had a dramatic localized failure at the specific location where FWD measurements taken three weeks earlier showed significantly reduced stiffness in the pavement structure. These four sections displayed the lowest average composite stiffness of all sections on the mainline pavement when they were new and they failed in order of increasing stiffness. Likewise, a FWD profile of Section 390101 after it had failed and been closed to traffic indicated that the lowest stiffness was in the most severely distressed area.

Conclusions

Based upon results obtained thus far on the Ohio SHRP Test Road, it appears that stiffness measured on the base and subgrade with the FWD is a much better representation of load carrying capacity than density and moisture measured with the nuclear density gauge. Also, this stiffness is a composite of the entire pavement structure in place at the time the measurements were taken, rather than just the top lift of material. Because FWD measurements are quite sensitive, they may also be used on in-service pavements to assess overall structural integrity, to identify localized areas of weakness which may require special attention prior to or during a major rehabilitation, and to design overlay thickness. Governmental agencies responsible for maintaining highway infrastructure should consider the measurement of stiffness to evaluate and monitor pavement condition.

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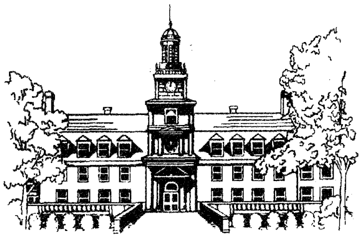

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